NASA Technical Memorandum 103143

High-Temperature Test Facility at the NASA Lewis Engine Components Research Laboratory

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(NASA-TM-103143) HIGH-TEMPERATURE TEST FACILITY AT THE NASA LEWIS ENGINE COMPONENTS RESEARCH LABORATORY (NASA) 22 p CSCL 14B

N90-25151

Unclas

G3/09 0291548

June 1990

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ENGINE COMPONENTS RESEARCH LABORATORY

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SUMMARY

The high-temperature test facility (HTTF) at NASA Lewis Research Center's Engine Components Research Laboratory (ECRL) is presently used to evaluate the survivability of aerospace materials and the effectiveness of new sensing instrumentation in a realistic afterburner environment. The HTTF has also been used for advanced heat transfer studies on aerospace components.

The research rig uses pressurized air which is heated with two combustors to simulate high-temperature flow conditions for test specimens. Maximum air flow is 31 pps. The HTTF is pressure rated for up to 150 psig. Combustors are used to regulate test specimen temperatures up to 2500 °F.

Generic test sections are available to house test plates and advanced instrumentation. Customized test sections can be fabricated for programs requiring specialized features and functions.

The high-temperature test facility provides government and industry with a facility for testing aerospace components. This report describes its operation and capabilities.

E-5495

INTRODUCTION

Advanced jet engines will be providing more thrust at greater engine efficiencies by operating at higher temperatures and using lighter weight, more durable engine components. New developments in component materials include advanced ceramic coatings, bonding agents, and base materials. These new materials must be tested in actual jet engine environments and subjected to both thermal and flow energies at simulated jet engine operating conditions. In addition, high-temperature instrumentation (strain gages and thin-filmed thermocouples) must be developed to monitor and analyze the hot engine components.

The high-temperature test facility (HTTF) at NASA Lewis Research Center's Engine Components Research Laboratory (ECRL) provides government and industry with a facility for testing aerospace materials, advanced instrumentation, and engine components exposed to temperatures and flows as high as 2500 °F and 31 pps, respectively. This report describes the operation and capabilities of the HTTF.

HIGH-TEMPERATURE TEST FACILITY SYSTEMS

The high-temperature test facility has a number of critical systems which must work together to attain desired test conditions. These systems include the air, fuel, and water systems. Their capabilities are outlined in table I. The following section describes these support systems.

Air System

The high-temperature test facility (figs. 1 and 2) uses pressurized air (150 psig) supplied through the central air system. It can vent to the atmosphere or into the altitude exhaust equipment which can provide a vacuum of up to 26 in. of mercury (2 psia).

A schematic of the air system is shown in figure 3. The pressurized supply air is filtered through a 50-μm filter assembly and the dew point level is maintained between -15 to -144 °F by means of dehydrators. Air enters the tunnel and branches into two lines. The smaller bypass line houses the J-47 combustor. A controlled airflow rate, using valve A, of up to 22.4 pps is heated in the combustor. The downstream end of the J-47 combustor then rejoins the main air line controlled by valve B. Valve B can regulate airflows up to 31 pps through the main air line. The resultant airflow and temperature of the ambient main air and the hot bypass air combined is maintained under 31 pps and 500 °F, respectively, by adjusting valve A, valve B, and fuel into the J-47 combustor. This arrangement allows a second J-58 combustor to burn more efficiently with less soot development and buildup. Preheated air travels approximately 20 ft before entering the J-58 combustor.

If temperatures above 500 °F are required in the test section, the J-58 combustor is used. The J-58 combustion air exhaust is controlled between 700 and 2500 °F. The controlled temperature accuracy is ±10 °F. The hot air travels through a water-cooled instrumentation section containing thermocouple and pressure probes and into the water-cooled test section. It is immediately quenched with water to a temperature of ~200 °F as it exits the test section. To adjust to different rig pressure conditions, the HTTF is equipped with exhaust control valves C and D. Downstream of the exhaust valves are additional water sprays to further cool the heated air down to 180 °F before it enters either the atmospheric exhaust stack or the altitude exhaust equipment. Twenty-six inches of mercury is the maximum vacuum maintained in the altitude exhaust system.

Photos of the main and bypass air lines, the water-cooled and quench sections, and the exhaust valves are shown in figures 4, 5, and 6, respectively.

Fuel System

The HTTF uses two jet engine combustors, a J-47 and a J-58, to heat the pressurized air to temperatures up to 2500 °F. The J-47 combustor burns either natural gas or Jet-A fuel. Each fuel requires a different J-47 combustor nozzle. The J-58 can burn Jet-A, JP-4, or JP-5 fuel.

A schematic of the fuel system is shown in figure 7. Three 20 000 gal underground fuel storage tanks house a variety of aviation fuels. These tanks are equipped with pumps for supplying the facility with 70 psig pressure. The 70 psig fuel supply is then fed to a second high-pressure fuel pump. To provide proper combustor nozzle spray formation, the fuel supply pressure out of the high-pressure pump is regulated between 500 and 600 psig. The maximum fuel flow rate is 10 gpm.

The jet fuel is cooled with 150 psig cooling water through a heat exchanger. The fuel is water-cooled because its continuous recirculation back through the high-pressure fuel pump causes heat buildup.

The J-47 combustor utilizes either a 190 psig natural gas supply or the J-58's jet fuel supply to preheat the bypass air in order to increase the J-58's burning efficiency. Once the fuel flow to the J-47 is set, only the fuel flow to the J-58 is regulated to adjust to different temperature conditions during a test run.

The J-58 exit temperature is controlled in order to achieve the required test specimen temperature. This is accomplished by regulating the J-58 combustor fuel flow either manually or automatically with a programmable controller. Temperature cycling tests can be accomplished by using the automatic mode. In the automatic mode, the operator first manually sets the desired high flow condition with the fuel-regulating valve A, and then adjusts the bypass fuel-regulating valve B to starve fuel from the J-58 combustor for the low fuel flow condition. Once both valves are set manually, the programmable controller operates shutoff valve C in the bypass fuel line. Temperature cycling is achieved by opening and closing valve C.

Temperature Profile Out of J-58 Burner

A typical temperature profile coming out of the J-58 burner at a 1800 °F average temperature is shown in figure 8. This radial temperature differential is characteristic of this type of combustor. In addition, the temperature profiles may be slightly skewed. The particular temperature pattern in figure 8 is, on average, hotter in the lower right quadrant. This is attributed to uneven burning and/or mixing from a slightly deformed or misaligned combustor.

Since a radial distribution of temperature exists, a radially weighted temperature is calculated when setting a temperature condition. Four thermocouple rakes (fig. 9) are used for this calculation.

Water Cooling System

Cooling tower water (150 psig) up to 600 gpm is supplied for cooling the HTTF hot sections and the jet fuel heat exchanger, and for quenching the combustion air downstream of the test section. A schematic of the water cooling system is shown in figure 10. The HTTF's water-jacketed instrumentation section and typical water-jacketed test section are cooled with a flow rate of 80 gpm each. The inside wall temperature of a typical water-jacketed section is usually about 200 °F. Exit water temperature in the cooling tower return line is less than 100 °F.

In addition, cooling water is used to quench hot exhaust air downstream of the test section where temperatures can reach up to 2500 °F. The exhaust is first quenched with up to 120 gpm of water to 200 °F by means of a spray ring and water jet nozzles located downstream of the test section. The airflow then passes through a secondary spray cooling assembly where it is cooled to 180 °F. This 180 °F temperature is the NASA Lewis limit for safely expelling air to the atmospheric exhaust stack or altitude exhaust equipment.

City water (50 psig) is used to cool the pressure and temperature probe housings in the instrumentation section downstream of the J-58 combustor. Photographs of the spray ring and jet nozzles are shown in figure 11.

Data Acquisition and Recording System

A computer system (ref. 1) is used to record, calculate, and display results during a test run. The HTTF's data system schematic is shown in figure 12. FM magnetic tape recorders, recording oscillographs, and gas analysis equipment are available in the control room (fig. 13).

During a test run, the operations engineer, researchers, and test operators utilize computer monitor displays located in the control room. These displays show air and fuel flow rates, and temperatures and pressures in either engineering units or raw data form (voltages or frequencies). The computer program handles 120 voltage and frequency signals. Typically, 6 flowmeters, 62 thermocouples, and 27 pressure transducers monitor and collect necessary data from the rig and test specimen. Scanning 120 signals and performing calculations take 1 sec. Therefore, 1 sec is the update rate for all display screens. Data displayed on the monitors can be recorded by the data file generation feature. Snapshots of the data can be recorded for later retrieval. Laser print copies of data are also obtained during a test run.

Analog recording on magnetic tape is available for taking transient data. Depending on the research requirements, gas analysis equipment is used to measure hydrocarbons, CO, CO_2, NO_x, O_2, and N_2 in the HTTF airstream.

FACILITY SAFETY FEATURES AND PRECAUTIONS

The HTTF has many safety interlocks which prevent it from reaching a potentially unsafe or destructive mode. The HTTF's control logic was designed such that if the rig did reach a dangerous mode it would automatically take action to safely handle any critical situation. Less critical situations would simply trigger an alarm.

One of the most important parameters that is monitored is temperature. The HTTF was designed to operate at maximum temperatures of 1500 and 2500 °F out of the J-47 and J-58 combustors, respectively. If these exhaust temperatures are reached, the rig's control logic will automatically shut off fuel to the combustor that is overheating. Combustor over-temperature can occur from loss of combustion air (which would increase the fuel-to-air ratio and thus the temperature), mechanical malfunction, and operator control errors. Upon shutdown, the combustor undergoes an automatic 60 sec air purge and its fuel nozzle undergoes a 60 sec nitrogen gas purge. This is done to ensure that no unburnt fuel remains in the system.

Another critical automatic shutdown is low combustor exit temperature. A J-47 and J-58 combustor exit temperature that is lower than 400 and 600 °F, respectively, indicates that the combustor is burning incompletely. This usually happens if there is a combustor flameout or if light-up is unsuccessful. Another shutdown is a low airflow shutdown. A sudden drop in flow will increase fuel-to-air ratios in the combustors causing over-temperature conditions. The triggering point for this shutdown is dependent upon research requirements.

When situations are less critical than the ones described, alarms are used. Alarms include low cooling water pressure, high water sump level, and high exhaust temperature downstream of the water quench sections. The alarms take the form of audible signals and visual annunciator panels, or display screens which highlight critically exceeded parameters.

TEST SECTION CONFIGURATIONS

The HTTF can accommodate a number of test section configurations as long as they meet the limited test section gap of 67.5 in. (fig. 14). This gap must include a water quench section for cooling the airstream. Sixteen-inch, 150 psi mating flanges are required for a test section.

The most commonly used test section is the material test section (figs. 15 to 17) which is used to evaluate the survivability of advanced materials under various temperature conditions. It is a 16-in.-diam, 36-in.-long, stainless-steel water-cooled test section. A customized 16-in.-diam by 24-in.-long water quench section is attached downstream of the test section. The quench section then attaches to a 16-in.-diam S-duct. This particular test section can accommodate two 12-in. by 12-in. test plates. Holding fixtures are available to align one plate parallel and the second angled 15° to the airflow.

Newer versions of this test section, currently being developed, will incorporate a radar horn to indicate plate degradation or failure. The radar horn is able to transmit and receive microwave signals. The horn sits on top of the test section and is separated from the hot exhaust air by a quartz window and bounces microwave signals off the test plates during a test run. Return microwave signals, picked up by the same radar horn, would provide an indication of test plate wear.

Another test section is the flat plate test section (fig. 18), which utilizes high-temperature, thin-film thermocouples to evaluate boundary layer heat transfer properties (fig. 19).

CONCLUSION

The high-temperature test facility at the NASA Lewis Research Center has been operating successfully for over 15 years and has given researchers valuable information on new high-temperature materials, instrumentation, and heat transfer studies in realistic afterburner environments at temperatures to 2500 °F. The rig's flexibility makes it useful to aerospace researchers in both industry and government.

Researchers interested in using the high-temperature test facility should contact the ECRL Facility Manager, Facilities Management Branch, Aeropropulsion Facilities and Experiments Division.

REFERENCE

1. Fronek, D.L., et al.: A Distributed Data Acquisition System for Aeronautics Test Facilities. NASA TM-88961, 1987.

TABLE I. - HIGH-TEMPERATURE TEST FACILITY SUPPORT SYSTEMS CAPABILITIES

HTTF systems	Flow rating	Pressure rating, psig
Supply air	31 pps	150
Aviation fuel	10 gpm	1000
Natural gas	0.15 pps	190
Cooling water	600 gpm	150

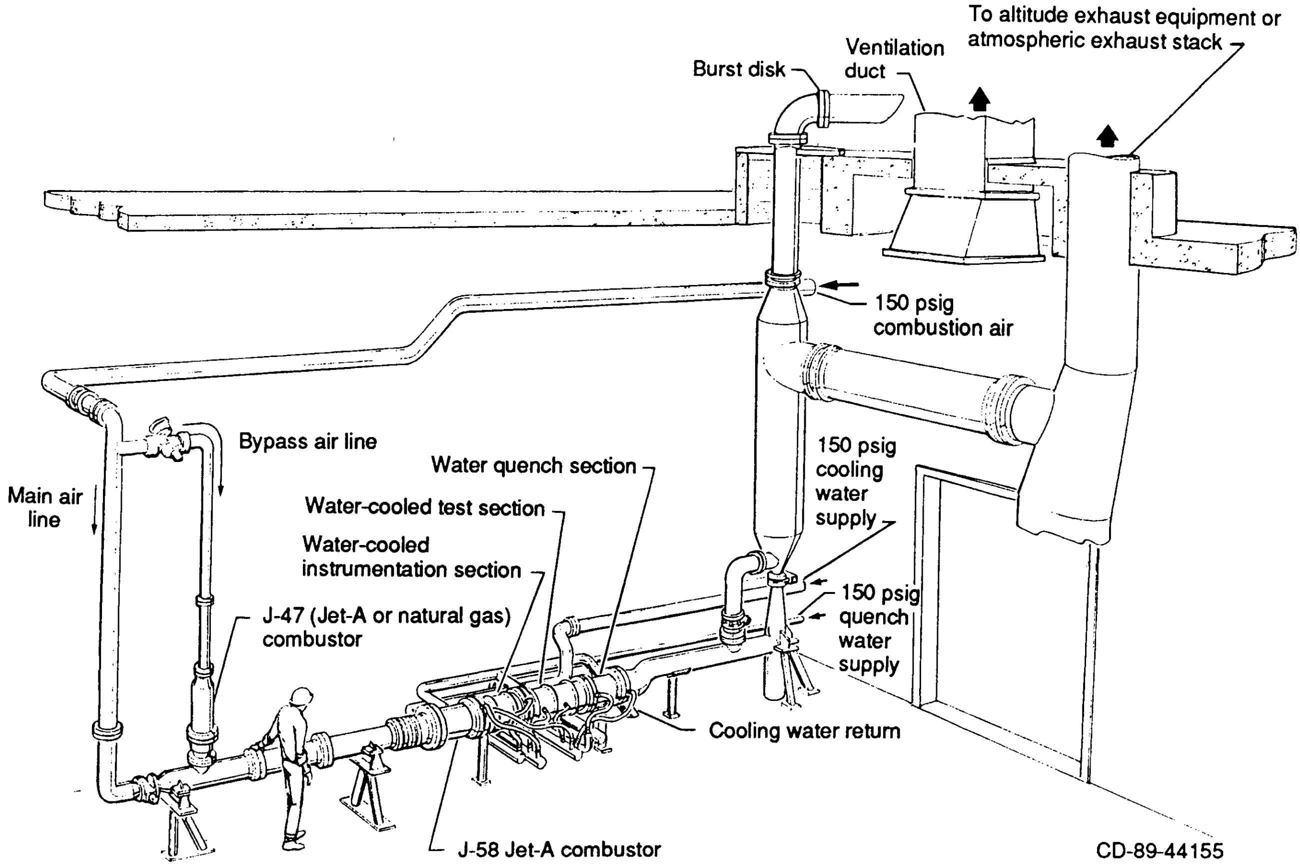

Figure 1.—The high-temperature test facility at the NASA Lewis engine components research laboratory.

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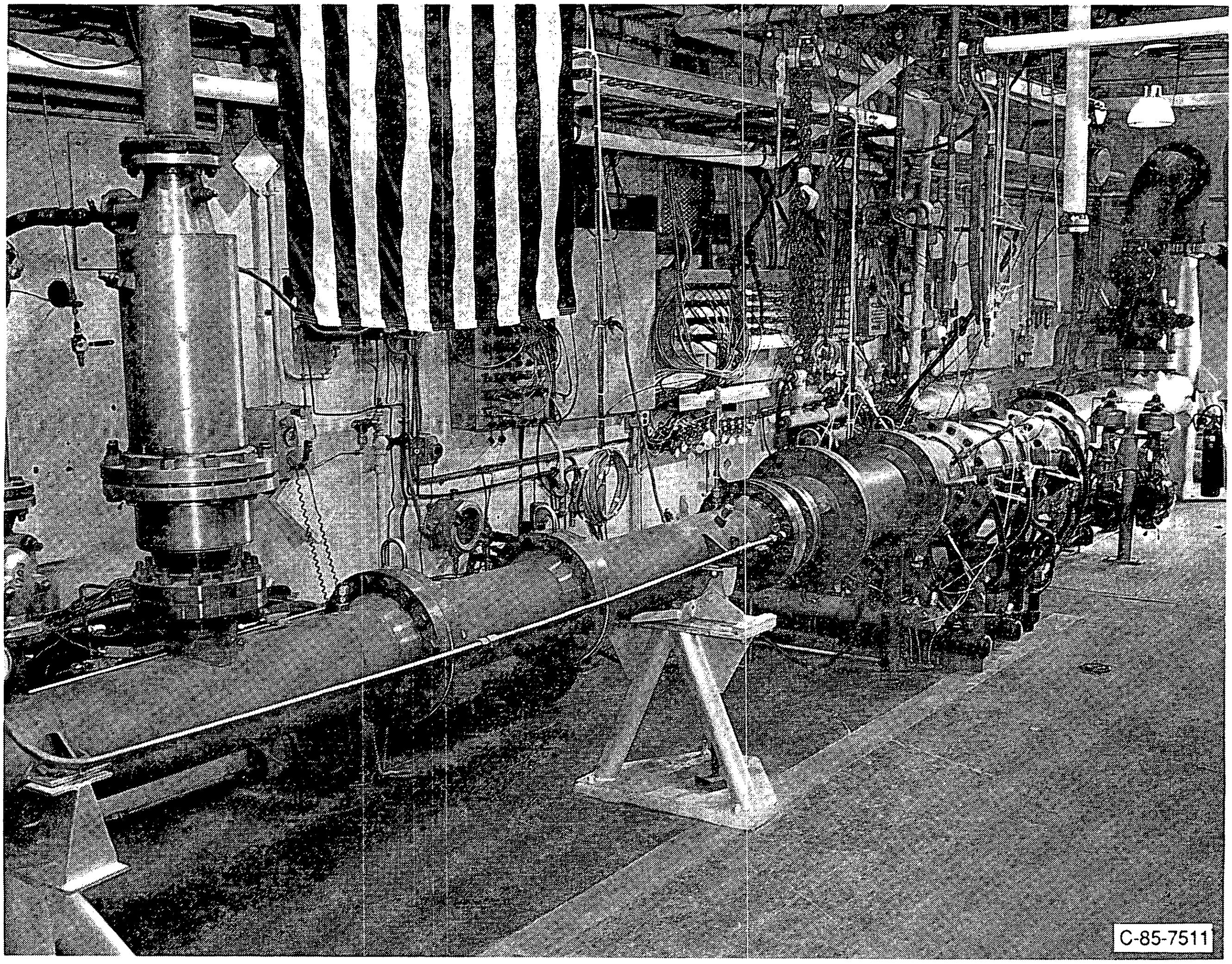

Figure 2.—High-temperature test facility with materials test section.

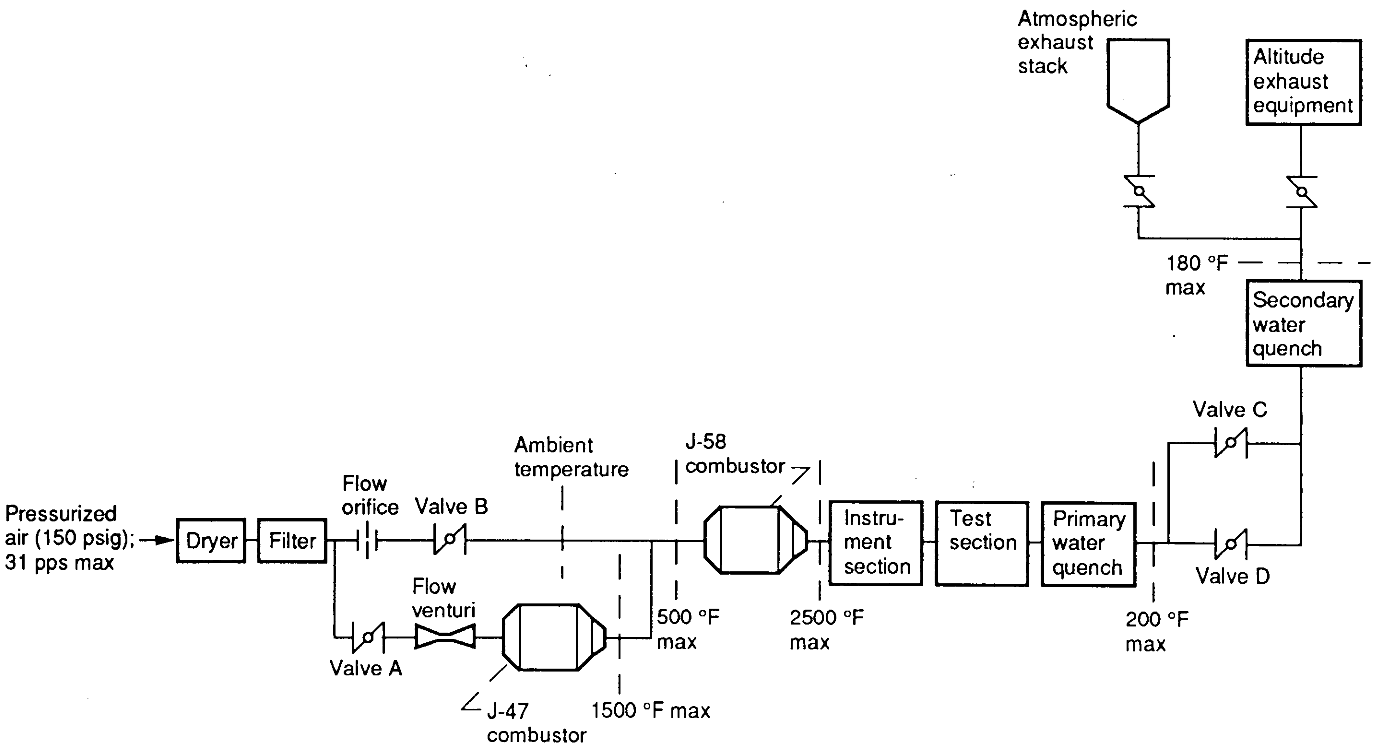

Figure 3.—Airflow schematic of high-temperature test facility.

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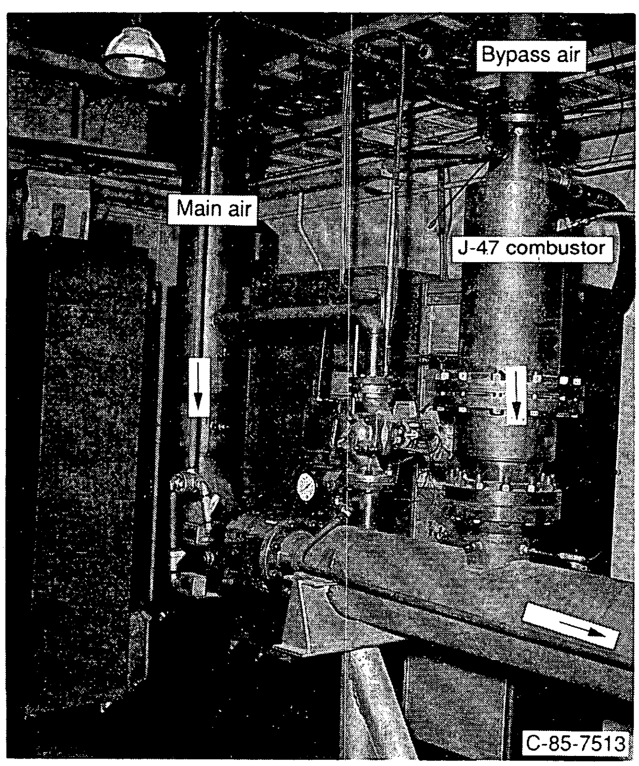

Figure 4.—Main and bypass air lines with the J-47 combustor.

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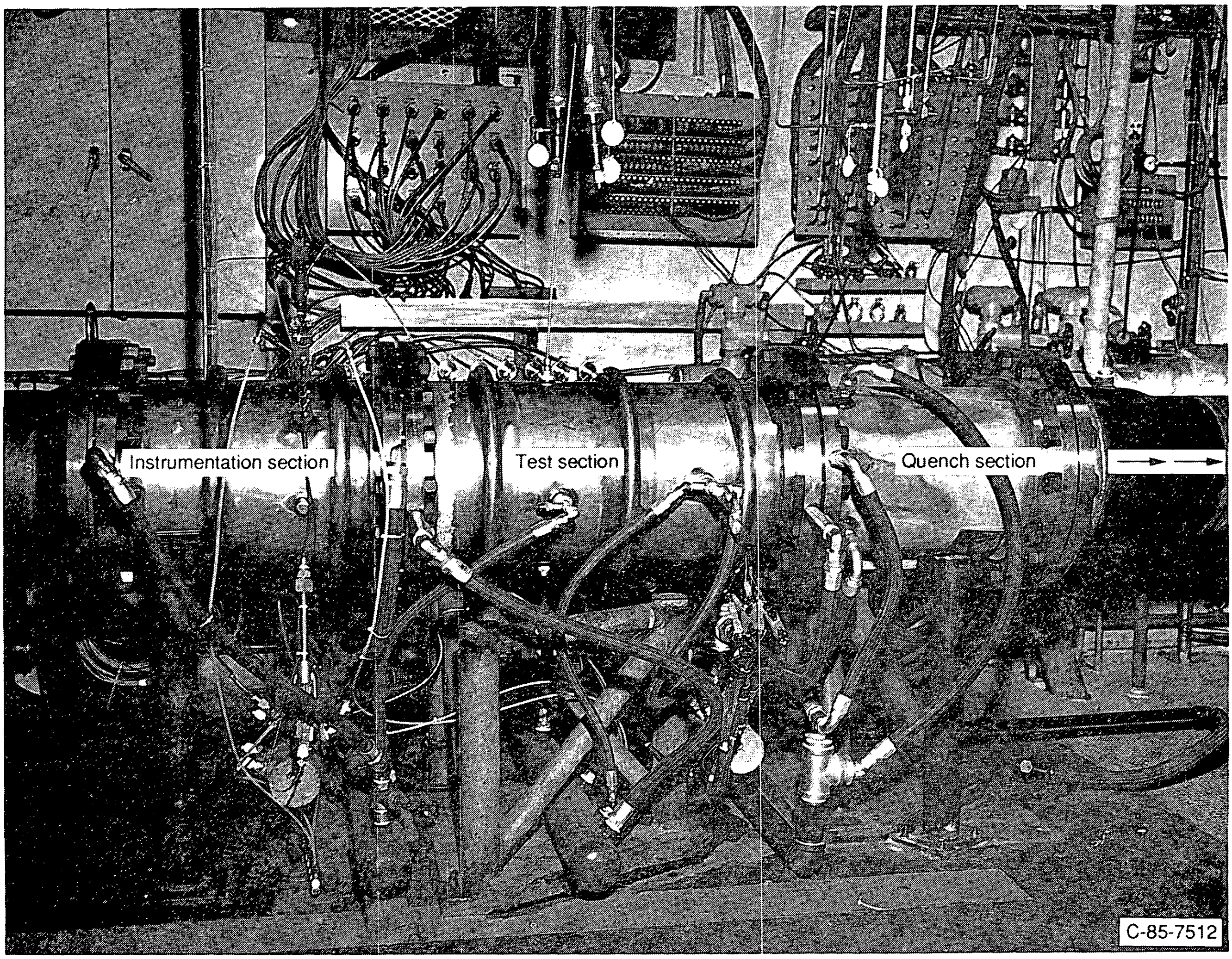

Figure 5.—Water-cooled sections of high-temperature test facility.

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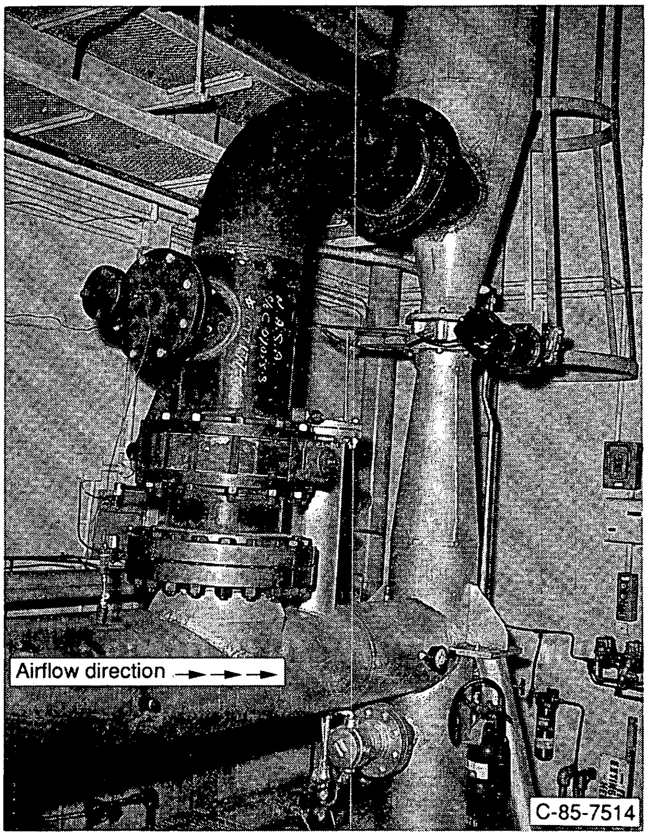

Figure 6.—Exhaust control valves that regulate high-temperature test facility back pressure.

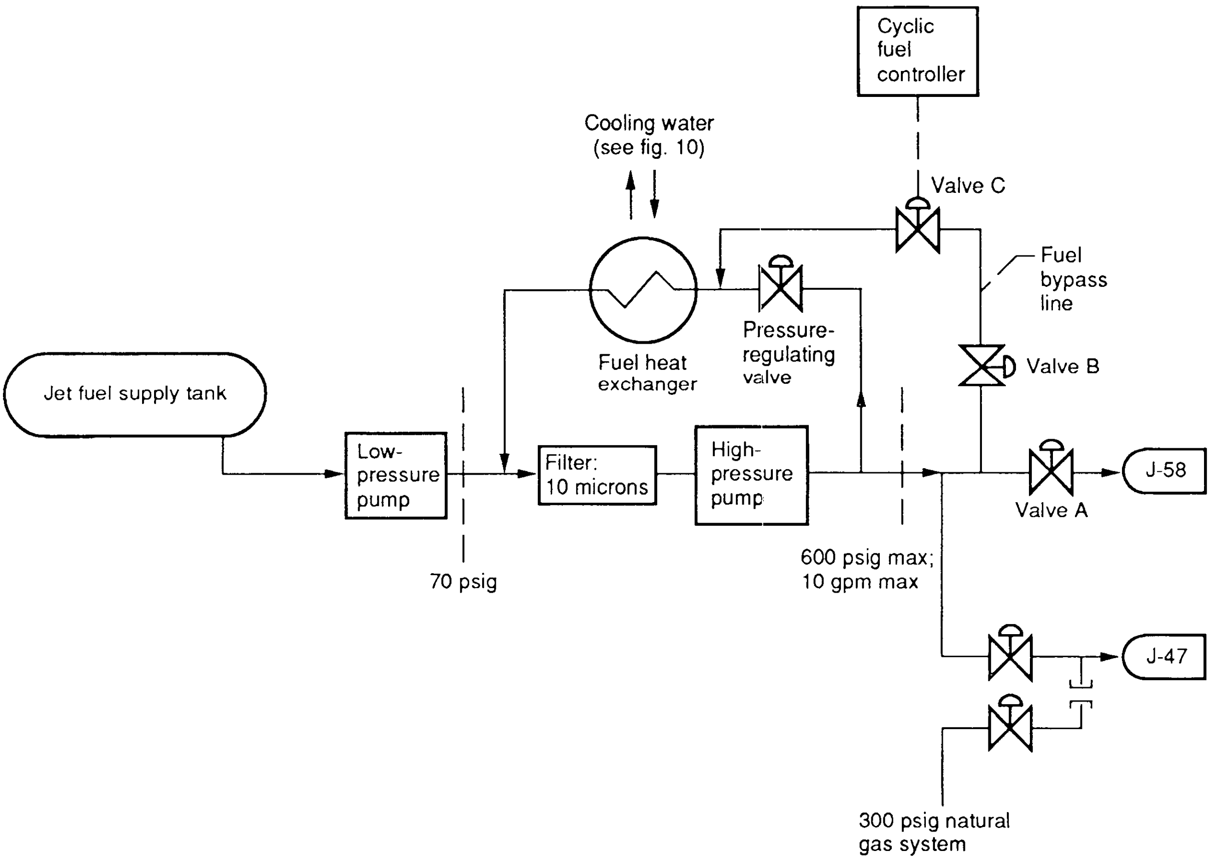

Figure 7.—Fuel flow schematic of high-temperature test facility.

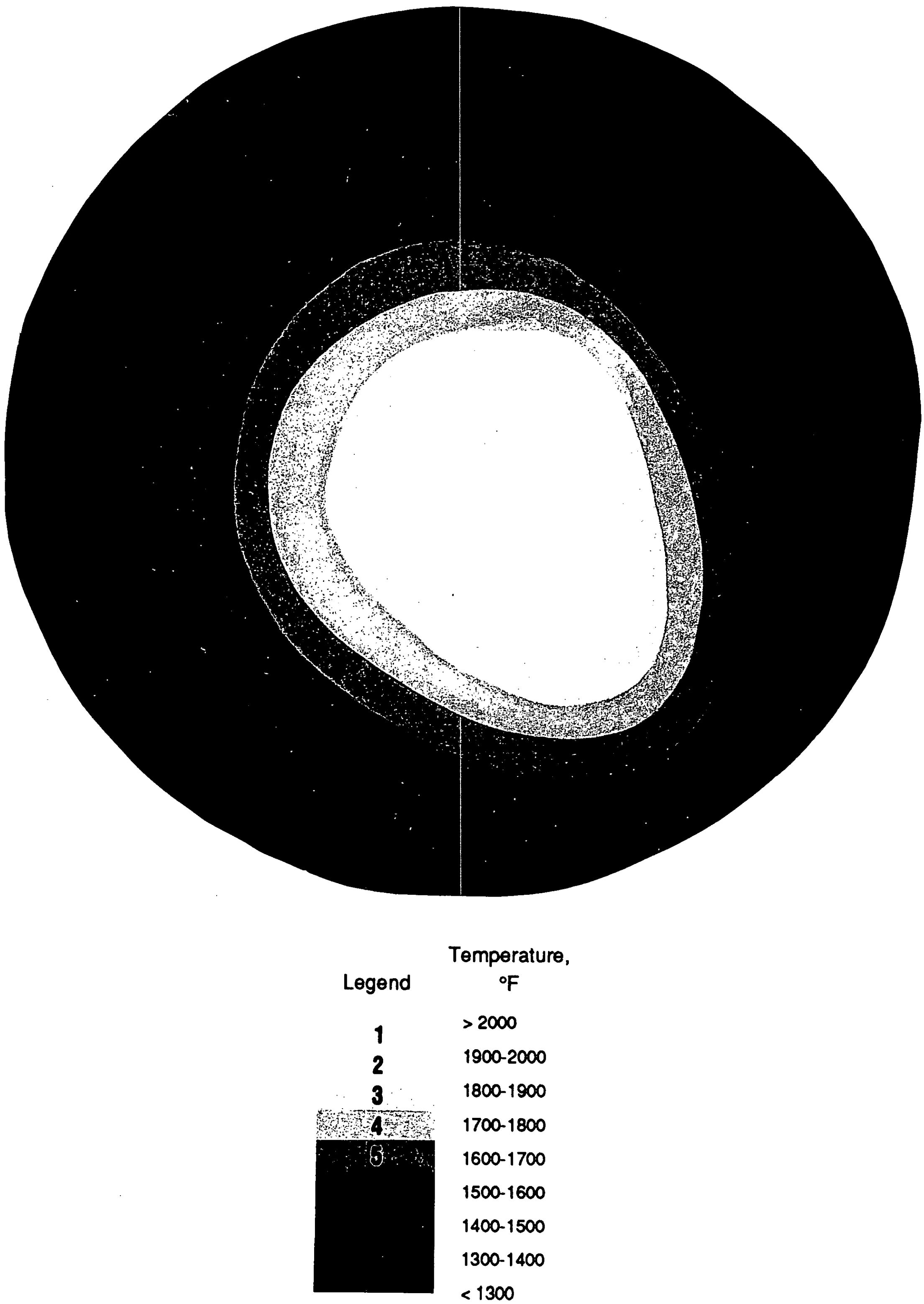

Figure 8.—Typical temperature profile looking upstream of test section.

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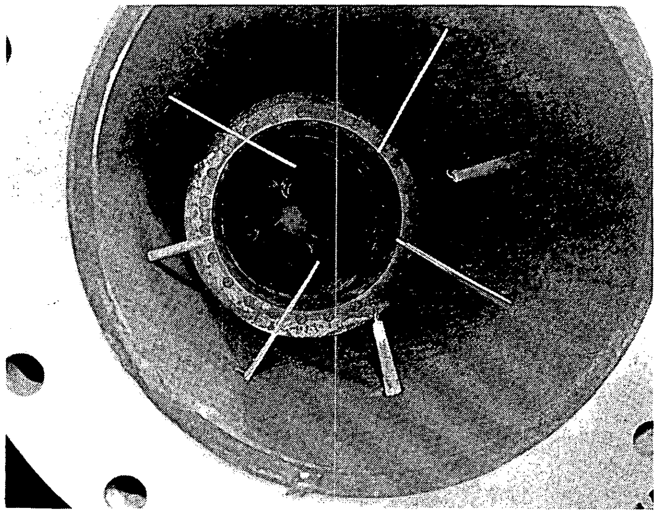

Figure 9.—View of J-58 combustor, thermocouple rakes, and water-cooled total pressure probes upstream of test section.

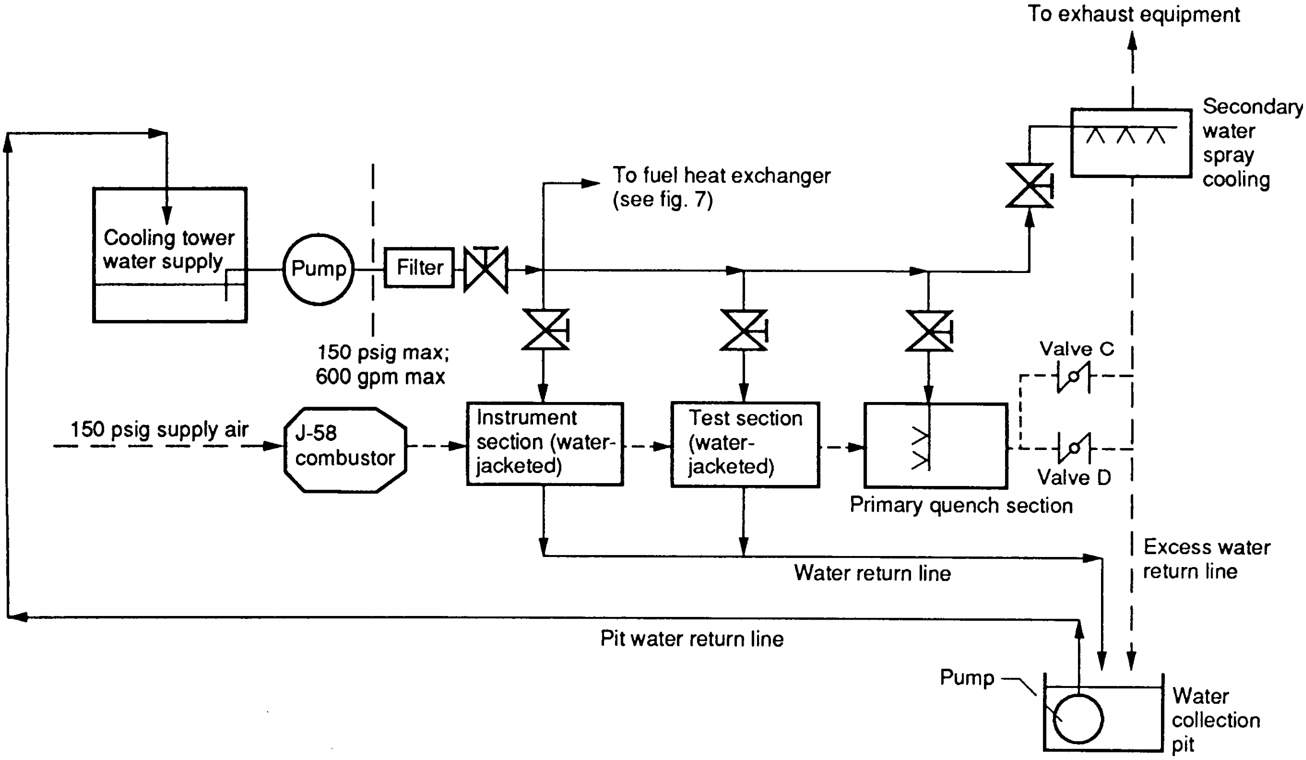

Figure 10.—Water flow schematic of high-temperature test facility.

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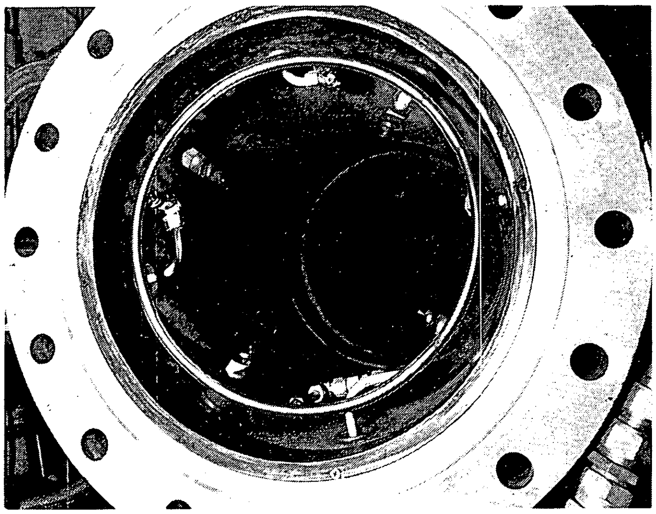

Figure 11.—Water spray ring and nozzles in quench section downstream of test section.

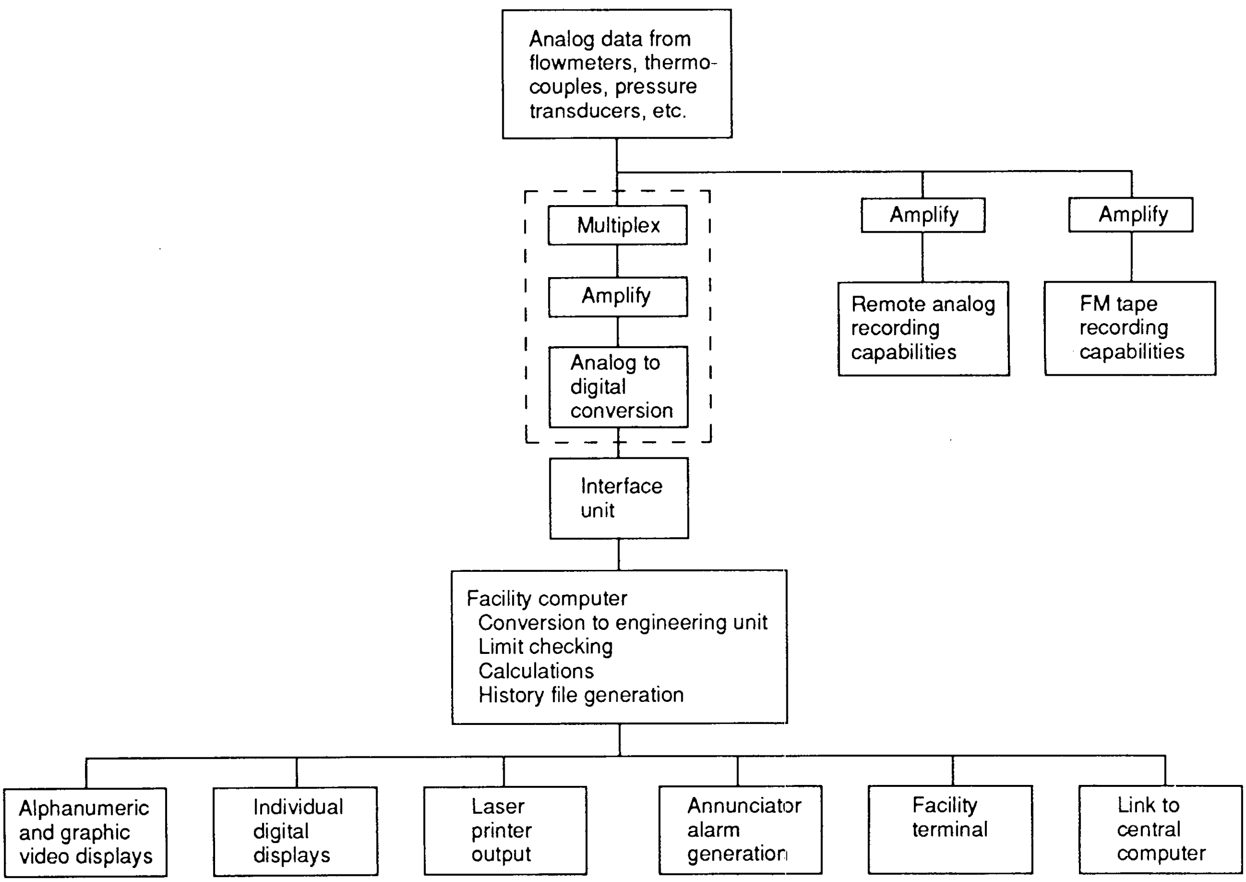

Figure 12.—Data system schematic for high-temperature test facility.

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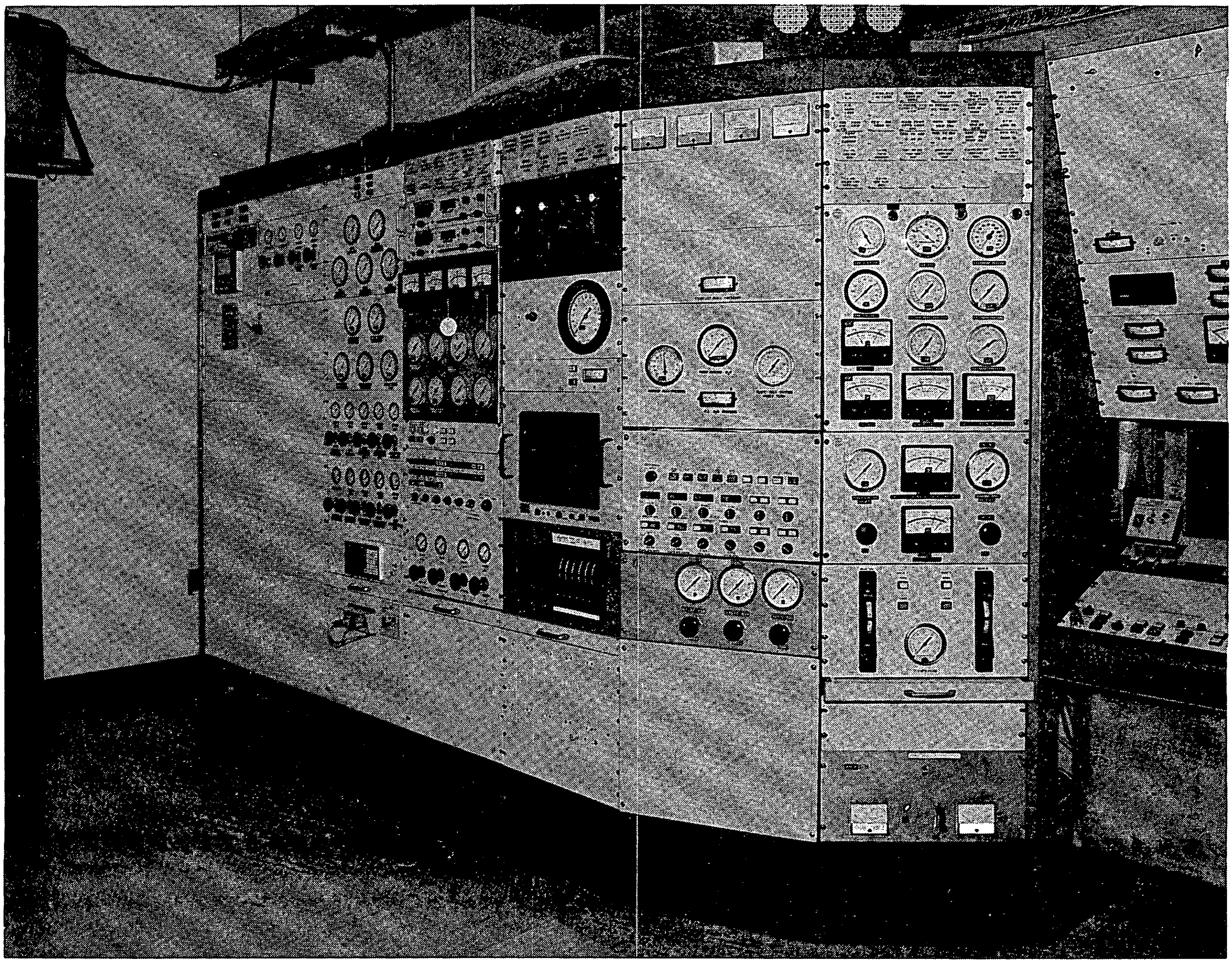

Figure 13.—Control room in engine components research laboratory for operating high-temperature test facility.

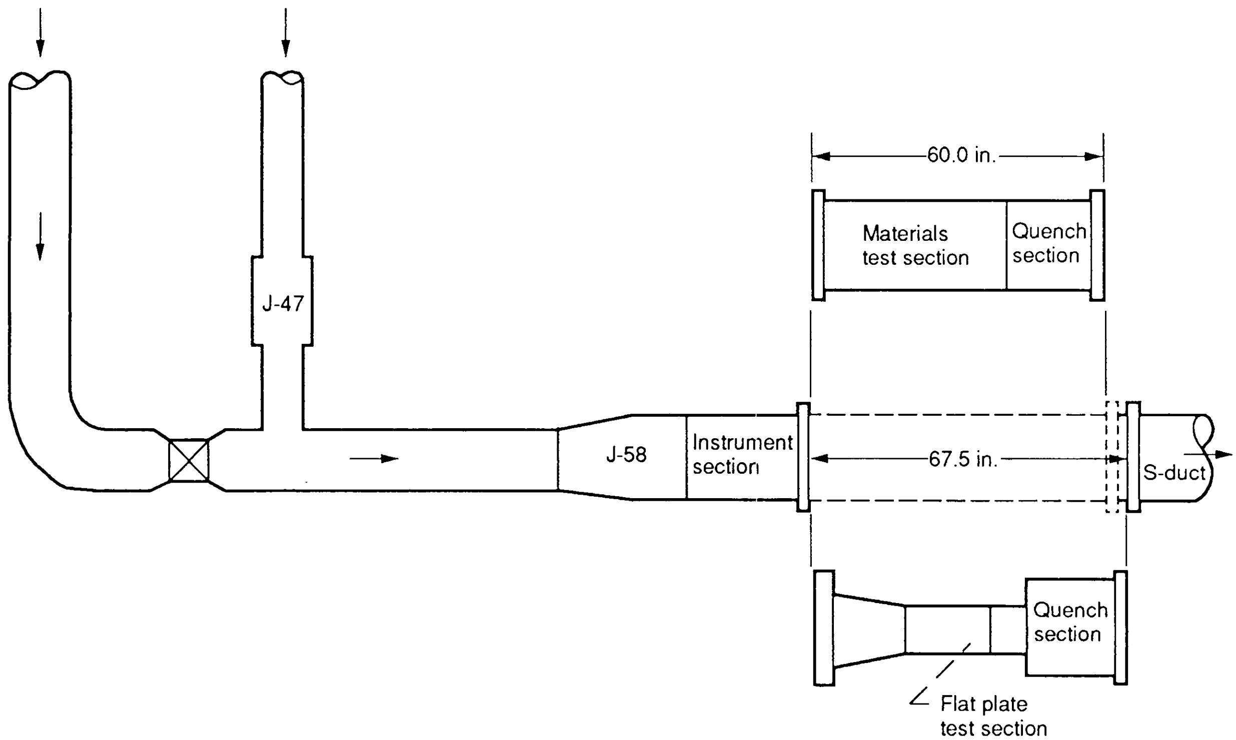

Figure 14.—Test section gap allocation of high-temperature test facility.

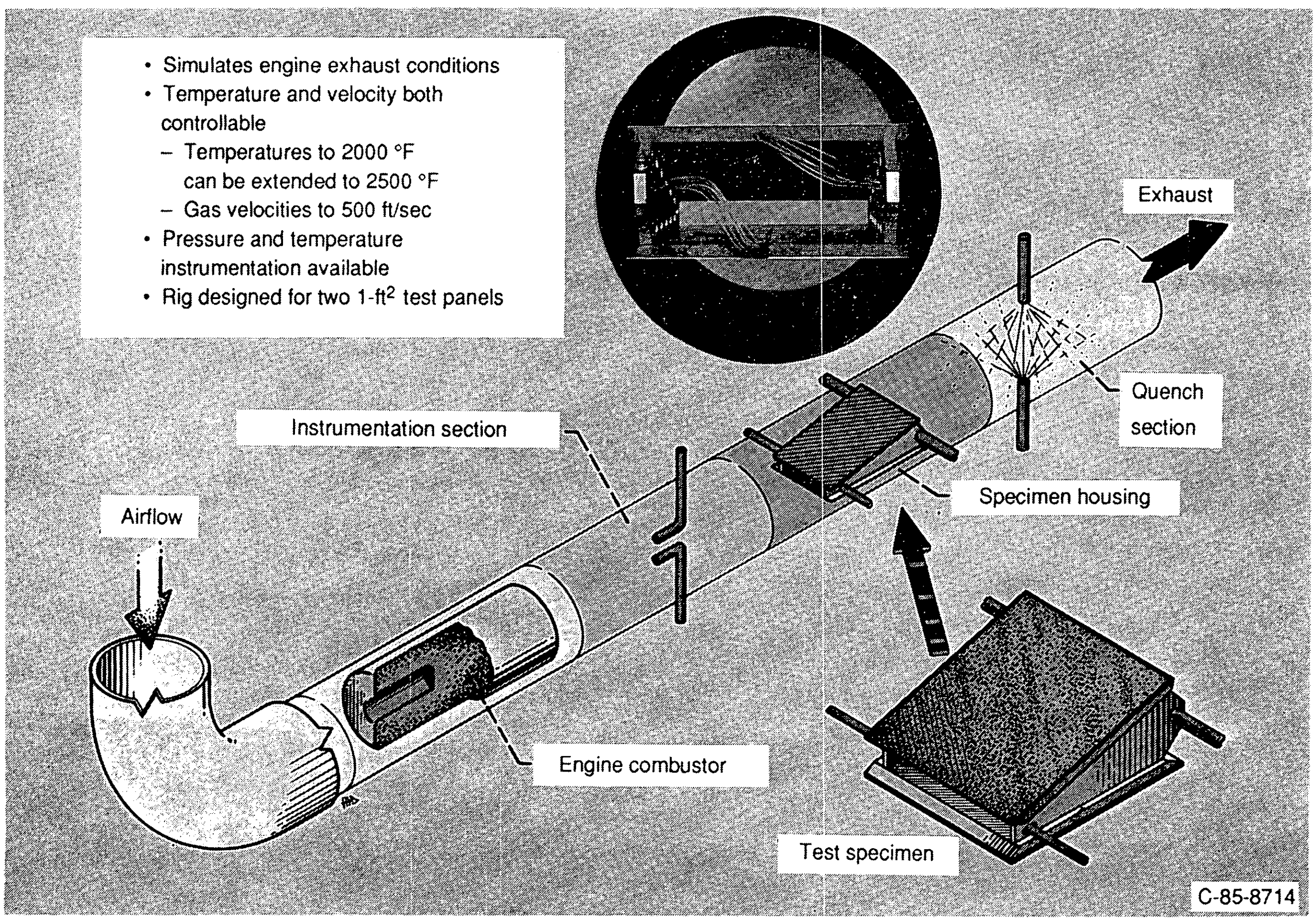

Figure 15.—Coating evaluation rig.

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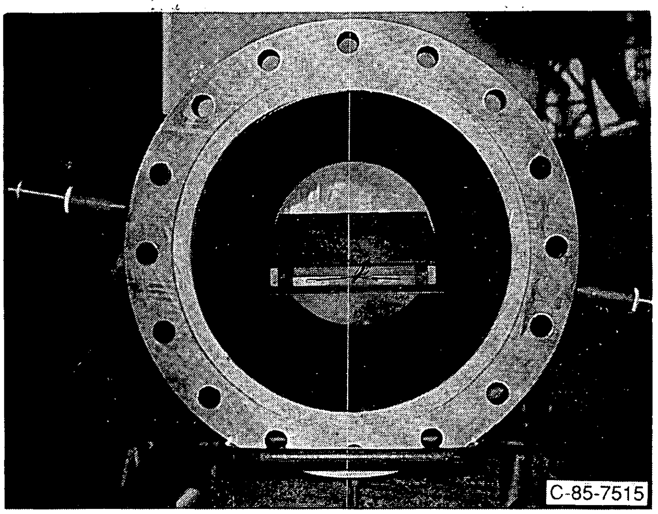


Figure 16.—Materials test section with thermocouple instrumented test plates looking downstream.

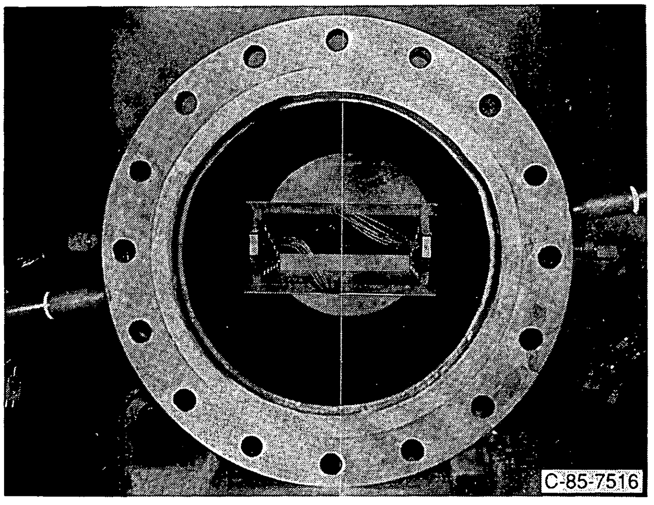
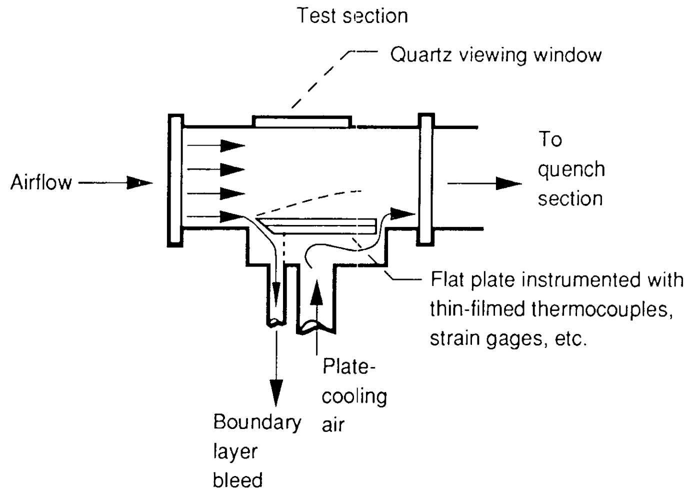


Figure 17.—Material test section looking upstream.



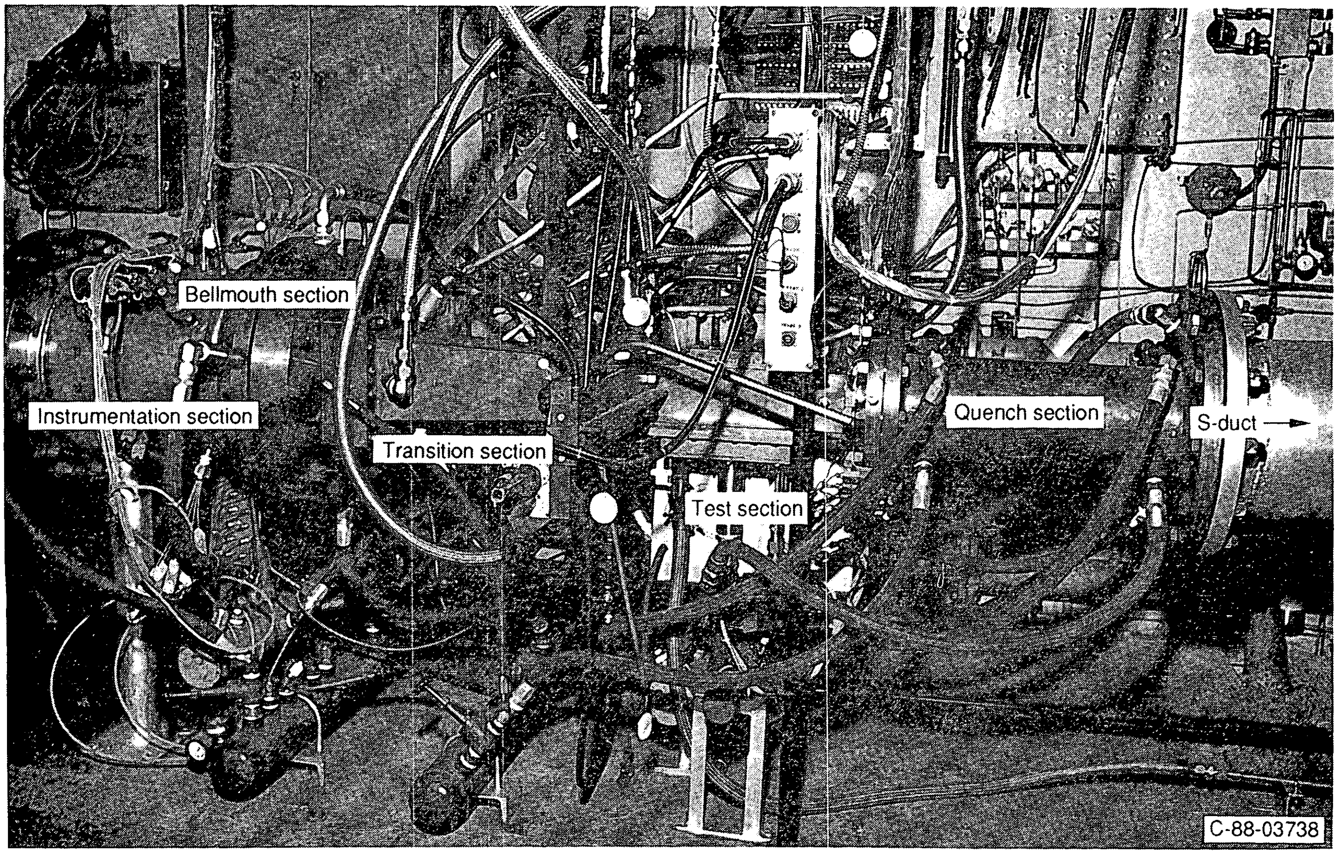


Figure 18.—Flat plate test section assembly for studying heat transfer characteristics.

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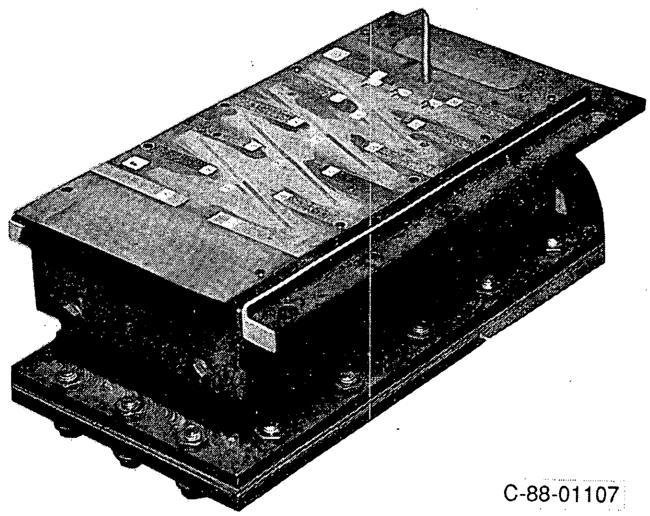

Figure 19.—Test specimen using thin-filmed thermocouples for advance heat transfer studies on flat plate test program.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-103143		

4. Title and Subtitle	5. Report Date
High-Temperature Test Facility at the NASA Lewis Engine Components Research Laboratory	June 1990
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Renato O. Colantonio	E-5495
	10. Work Unit No. 505-62-3B
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
High-temperature test facility Materials test facility	Unclassified – Unlimited Subject Category 09

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	22	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161